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Preliminary communication

FLOW INVESTIGATIONS ON THE SUBSTRATE DELIVERY SYSTEM IN A GAS BURNER

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Applied combustion systems should ensure the optimal safety of operation and required qualitative parameters of a technological process. Selection of the path equipment components is determined by pressure drops resulting from local flow resistances and by the utilisation requirements of a heated device. Their flow characteristics as well as methods for calculating pressure drops in the system and local resistance numbers are presented. The combustion process was found to influence a change in the airflow characteristics, limiting the potential for achieving the nominal power of the burner with no increased overpressure of the combustion air. The determined flow characteristics and local resistance number values can be used for the algorithms of burner designs in order to obtain optimal operating parameters.
Key words: gas burner, substrate delivery system, resistance number.

Tijek ispitivanja sustava isporuke supstrata u plinski gorionik. Sustavi primijenjenog izgaranja trebaju osigurati optimalnu sigurnost rada i potrebne kvalitativne parametre tehnološkog procesa. Izbor dijelova opreme određen je padom tlaka koji proizlazi iz lokalnih otpora strujanju i zahtjevima iskoristivosti zagrijavanih uređaja. Prikazane su njihove karakteristike protoka, kao i metode izračuna pada tlaka u sustavu i lokalni faktori otpora. Utvrđeno je da proces izgaranja utječe na promjene karakteristika protoka zraka, ograničava potencijal postizanja nazivne snage gorionika bez povećanja predtlaka izgaranja zraka. Određene karakteristike protoka i lokalne vrijednosti faktora otpora mogu biti korištene za algoritame dizajna gorionika, kako bi se dobili optimalni radni parametri.
Ključne riječi: plinski gorionik, sustav isporuke supstrata, faktor otpora.

INTRODUCTION

A gas burner is a device which delivers defined amounts of gas fuel and oxidiser to the combustion zone as well as stabilises the flame at its outlet and ensures it has required parameters, i.e. a proper shape and, determined by the heating process, an appropriate level and a balanced distribution of temperatures. It also generates a furnace atmosphere composition which is determined by technological parameters. To meet these requirements, the burner parameters should be controlled in a way that ensures the optimal course of combustion and heat transfer processes. Due to the combustion process characteristics, it is important whether combustion occurs under unsteady state, fluctuating or steady state conditions as well as if it proceeds in the diffusive or kinetic region. Applied combustion systems should ensure the optimal safety of operation and required qualitative parameters of a technological process [1-3]. The equipment of so-called gas and air paths satisfies the EN-746-2 safety standard and allows for its use in a few burners of a given furnace zone [4]. A burner with the nominal power higher than 0.14 MW should be activated when its start-up power does not exceed 50% of the nominal power. Automated and semi-automated unit burners, where the start-up power is larger than 0.14 MW, must be equipped with an ignition burner. The ignition burner power may be up to 5% of the main burner nominal power but it may not exceed 0.14 MW [5-10]. Gas burners that are intended for operating at temperatures lower than the ignition points, e.g. for certain processes of the charge material heat treatment, should have a flame control device which only responds to the flame of the controlled burner. Two types of the flame control devices, based on UV radiation (photocell) and flame ionisation (detection), are used. In the case of flame extinction, the applied control system triggers an immediate switch-off of the burner. When the burner is restarted, its flame should be stable within the whole range of required thermal power control with no lift-off or blowout. The burner should be ignited when the excess air coefficients are $\lambda \leq 1$, i.e. within the range of maximum, normal combustion rates [5]. A precise control of the gas burner operation requires the knowledge of flow characteristics of its gas and air nozzles. In the case of complex shapes of the gas and air burner outlet nozzles, their proper designs are only possible if the flow characteristic investigations have been conducted. Also, the stability range must be examined on the experimental basis due to the lack of calculation criteria for diffusion burners [1, 11]. The flow characteristics of the gas and air nozzles are also affected by the mutual arrangement of the combustion substrate outflow directions, values and ratios of the air and gas fuel velocities (w_a, w_g and w_a/w_g) as well as the combustion process itself. Due to the described complexity of flow characteristic investigations, designers of the burners develop their design series, i.e. designs whose powers depend on magnification of the unified geometrical shape scale.

CHARACTERISTICS OF THE SUBSTRATE DELIVERY SYSTEMS

To ensure required combustion parameters, a modern gas burner is equipped with complex, microprocessor-controlled devices intended for control and measurement, automated control and operation safety. The most complex unit is the gas path, i.e. the section extending from the fuel collector – the collecting pipe – to the burner. Essential components of the gas path are as follows (in the order from the collector to the burner): the main valve, gas filter, gas pressure control unit (reducer-stabiliser), electromagnetic valves, devices for the electromagnetic valve and gas path leak tightness control as well as the thermal security valves. Moreover, the gas path is fitted with auxiliary manual ball valves, gas and air pressure detectors, gas fuel-air ratio control units, pressure gauges, gas meters and flow meters, compensators etc. The gas paths of burners that operate in devices where combustion chamber temperatures are lower than 700°C should be equipped with a security system which protects from gas fuel outflow in the case of flame extinction. Selection of the gas path components mainly depends on the burner type, gas pressure in the collector, thermal power, the burner mode of operation, parameters of the device where the burner is to be installed, i.e. the furnace temperature, pressure in the working chamber and individual requirements of a user. According to the EN 746-2 standard, a gas path with proper equipment may deliver fuel not only to an individual burner, but also to a group of burners that heat the furnace or, for larger units, to a given zone of a heating furnace or a furnace intended for heat treatment [4, 7].

FLOW CHARACTERISTICS OF THE SUBSTRATE DELIVERY SYTEM

The design of gas and air paths that deliver combustion substrates to furnaces, i.e. their equipment containing required components, causes pressure drops in the system. They result from local resistances observed in individual components of the gas and air paths. To ensure proper pressure before installation and appropriate selection of the path components, it is necessary to know the pressure drop values. In Fig. 1, the flow characteristics of a GPP-5 flat flame burner for various combustion air preheat temperatures are presented [5, 19]. For the nominal power of the burner $\dot{Q}_{nom} = 800\ kW$, required air overpressure is as follows: for 20°C $\Rightarrow \Delta p_{a1}$ = 2.8 kPa, and for 600ºC $\Rightarrow \Delta p_{a6}$ = 7.6 kPa. As the flow characteristic investigations are mostly conducted for substrates at ambient temperatures, proper adjustments of manometric characteristics should be made during their preheating.

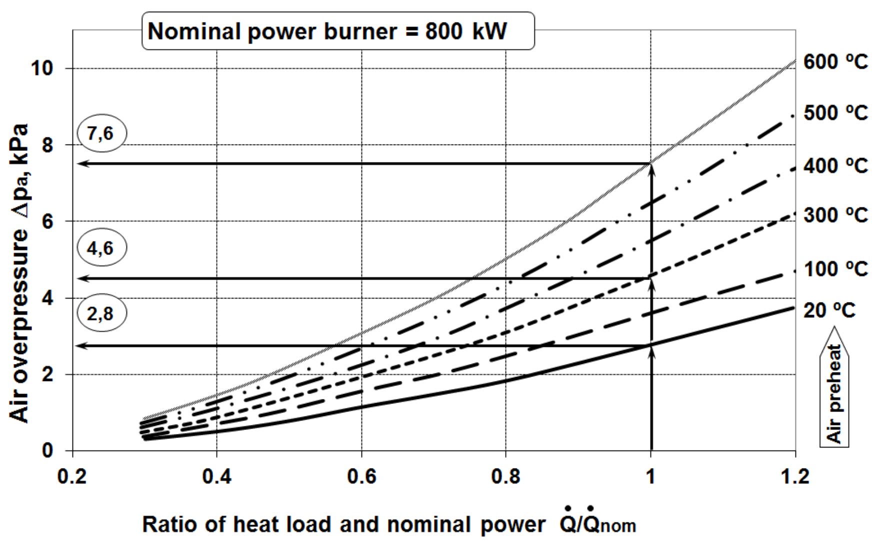

Figure 1. Flow characteristics of a GPP-5 flat flame burner for various ratios of the burner thermal load to its nominal power

Slika 1. Karakteristike protoka GPP-5 ravnog plamena gorionika za različite omjere toplinskog opterećenja gorionika na njegovu nominalnu snagu

The flow characteristics for an 80 kW burner in a drawing furnace, within the whole range of substrate parameter changes from the minimum to the nominal thermal power, are presented in Figs. 2 and 3. The flow characteristics were determined based on pressure ($\overline{\Delta p}_{a,g}$) and volume flow rate ($\bar{\dot{V}}_{g,a}$) average values for Δt = 60s. In the combustion process, extra resistance Δp = 134 Pa during the air outflow is generated which, as a consequence, leads to the airflow reduction by $\Delta\dot{V}_a = 101\ m_n^3/h$, i.e. by about 9.2% with respect to the non-combustion outflow. The natural gas outflow occurs via the front nozzle A_{gcz} = 28.26 mm^2 and boundary nozzles – 8 holes – A_{gob} = 39.25 mm^2, with the overall outflow surface area A_g = 67.51 mm^2. The air outflow occurs via the nozzle where the surface area is A_a = 593.9 mm^2. The air swirl angle is 45º.

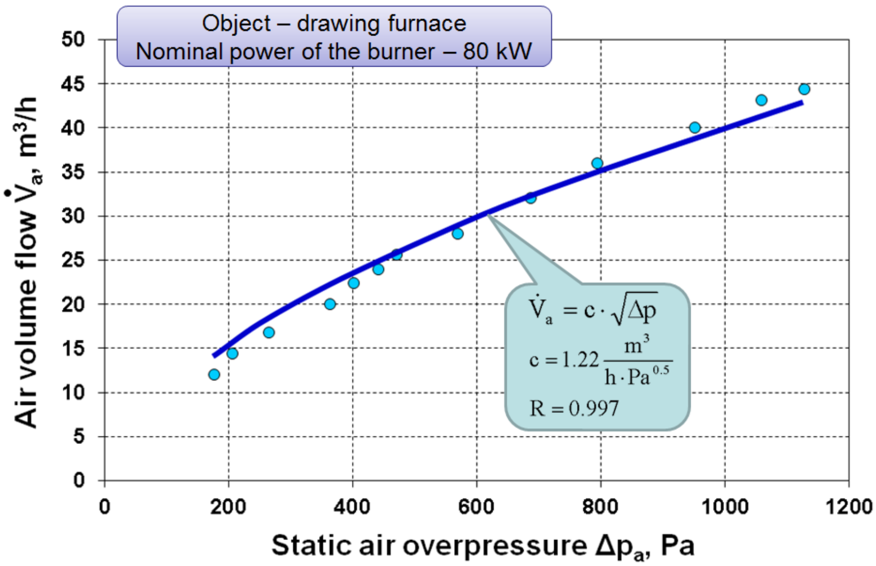

Figure 2. The air flow characteristics for an 80 kW burner in a drawing furnace
Slika 2. Karakteristike protoka zraka za 80 kW gorionik na crtežu peći

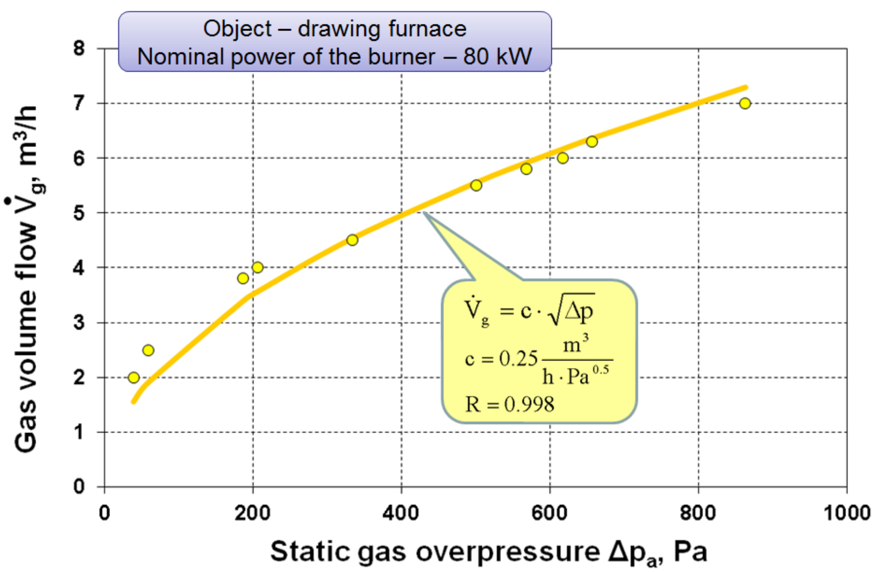

Figure 3. The natural gas flow characteristics for an 80 kW burner in a drawing furnace
Slika 3. Karakteristike protoka prirodnog plina za 80 kW gorionik u crtežu peći

LOCAL RESISTANCE NUMBERS (ξ)

Methods for pressure drop calculations in pipes mainly refer to their straight sections. For complex structures, such as: burner designs which contain components that cause changes in directions and cross-sections of the working media, measuring (orifices) and control (dampers, valves) elements, extra pressure drops, resulting from these local flow resistances, should be considered. A pressure drop caused by the local resistance is calculated based on the following equation:

$$\Delta p = \xi \frac{\rho w^2}{2}, \quad Pa \tag{1}$$

where: ρ – medium density, kg/m^3; w – outflow velocity, m/s, ξ – local resistance number. In a roughly manner, the pressure drop in the burner can be calculated by summing up individual pressure drops referring to the local resistances which result from the flow through characteristic elements that create the burner body [1]:

$$\Delta \mathrm{p} = \frac{\rho}{2} \sum \xi_i w_i^2, \quad \mathrm{Pa}. \tag{2}$$

Local resistance numbers for some characteristic burner components are presented in tables. For complex outlet nozzle shapes, however, the only possibility is conducting flow characteristic investigations. Equation (1) can be also expressed in a non-dimensional manner:

$$\mathrm{Eu} = \frac{1}{2} \xi, \tag{3}$$

where: Eu – Euler's number – $Eu = \Delta p/\rho w^2$. Thus, the ξ value is:

$$\xi = 2\mathrm{Eu}. \tag{4}$$

In gas burners, the substrate (air in particular) swirl is applied because it increases the stability and intensifies the mixing process, which results in a markedly shorter flame. In the literature, it has been shown that the resistance number does not depend on the air swirl angle if the following conditions are fulfilled: the free outflow surface area A_Z = const and the characteristic velocity is the axial component of the air velocity [11-13]. As the air temperature affects its density, it also influences the velocity of outflow from the burner. Moreover, considering the temperature function, the dynamic viscosity coefficient for the air is considerably altered. Raise of the air preheat temperature from 20 to 600ºC at $p_N = 1013$ hPa results in a nearly three-fold lower density and an over two-fold higher dynamic viscosity coefficient. A change in the combustion air temperature also affects the resistance number value. The calculations of the preheat temperature effects on the resistance number have shown that with respect to T = 293 K, the resistance number for 573 K is $\xi_{a573} = 0.84\xi_{a293}$, and the value for 873 K is $\xi_{a873} = 0.91\xi_{a293}$. This factor has a beneficial effect on the safety of air fan selection. However, the burner resistance number value is also influenced by the working space conditions, i.e. pressure and temperature, which may, in the case of significant overpressure, level the beneficial resistance number value or even markedly increase it. In Fig. 4, a scheme of resistance number (ξ) calculation is presented.

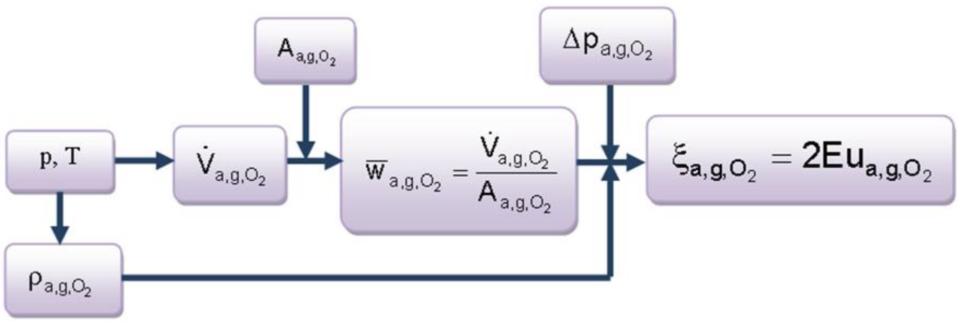

Figure 4. A scheme of resistance number (ξ) calculation
Slika 4. Shema izračuna faktora otpora (ξ)

Table 1 shows results of investigations on the ξ values for a multi-hole gas nozzle (number of holes n = 8) in a modernised Heurtey burner with the outflow surface area A_{gz} = 67.51 mm^2 during natural gas combustion. The gas flows were not swirled. The analysis of the resistance number values shows that they are contained within the range of ξ_{gz} = 1.49 – 2.79. These values were obtained for 8 holes with a diameter d_{gob} = 2.5 mm each and for the nozzle top with a diameter d_{gcz} = 6 mm.

Table 1. Resistance numbers for a multi-hole gas nozzle of a modernised Heurtey burner with A_{gz} = 67.51 mm^2 and no gas swirl α_g = 0° [7]
Tablica 1 Faktori otpora plinske sapnicu s više rupa u moderniziranom Heurteyevom gorioniku s A_{gz} = 67.51 mm^2 i bez plinskog vrtloga α_g = 0° [7]

Number and diameter of the holes at the periphery of the nozzle	**Number and diameter of the nozzle tops**	**Volume flow rate** $\dot{V}_g$, m^3_n/h	**Resistance number** ξ_g
8 ×ϕ2.5 mm	1 ×ϕ6 mm	2	1.56
		2.5	1.49
		3.8	2.04
		4.0	2.04
		4.5	2.61
		5.5	2.62
		5.8	2.67
		6.0	2.72
		6.3	2.62
		7.0	2.79

In Table 2, results of investigations on the resistance number (ξ_a) for an annular air nozzle with A_a = 593.9 mm^2 and the air swirl α_a = 45° are presented. The resistance number values fall within ξ_a = 4.01 – 8.68.

Table 2. Resistance numbers for an air nozzle in a modernised Heurtey burner with A_a = 593.9 mm^2 and the air swirl α_a = 45° [7]
Tablica 2. Faktori otpora zračne sapnice u moderniziranom Heurteyevom gorioniku s A_a = 593.9 mm^2 i zračnim vrtlogom α_a = 45° [7]

Number of the nozzle tops	Volume flow rate $\dot{V}_a$, m^3_n/h	Resistance number ξ_a
1	12.0	8.68
	14.4	7.01
	16.8	6.63
	20.0	6.42
	22.4	5.66
	24.0	5.41
	25.6	5.08
	28.0	5.13
	32.0	4.74
	36.0	4.33
	40.0	4.20
	43.2	4.01
	44.4	4.04

CONCLUSION

While selecting the gas and air path components, pressure drops within the whole range of the gas burner thermal power should be considered.

The flow resistance values for the substrate delivery systems are highly affected by:

- the equipment and designs of the substrate paths,
- substrate temperatures (900–1000°C in modern devices),
- pressures in the combustion chambers (100-500 Pa).

When the substrate swirl is applied, burner resistances and resistances of the entire substrate delivery system markedly increase.However, due to better burner stability, it is a widely used method for safe burner utilisation.

Fuel combustion in the working chamber of industrial furnace has a significant effect on the air nozzle characteristics as extra resistance is generated which can reduce the maximum airflow and force the burner to operate in lower thermal power settings.

The determined flow characteristics and local resistance number values can be used for the algorithm of burner designs in order to obtain optimal operating parameters.

REFERENCES

[1] Tomeczek J.: Spalanie i płomienie gazowe. Wydawnictwo Politechniki Śląskiej. Gliwice 1982.

[2] Tomeczek J.: Przemysłowe długopłomienne palniki na gaz ziemny. Konferencja międzynarodo-

wa SITPH. Kraków 1974, s. 156-162.

[3] Rozpondek M., Puszer A., Gradoń B.: Zasady doboru palników gazowych do pieców grzewczych. III Ogólnopolska Konferencja Naukowo-Techniczna p.t.: Gospodarka cieplna i eksploatacja pieców przemysłowych. Politechnika Częstochowska – Huta Częstochowa. Poraj 1995, s.167-171.

[4] Program produkcji firmy Kromschröder A.G. Symposium. Gliwice 24–25.11.1999. G. Kromschröder A.G. ITT GmbH.

[5] Tomeczek J., Rozpondek M.: Zasady eksploatacji dyfuzyjnych palników gazowych. IX Ogólnopolska Konferencja Naukowo-Techniczna p.t.: Gospodarka cieplna i eksploatacja pieców przemysłowych. Politechnika Częstochowska – Huta Częstochowa. Poraj 2001, s.263-272.

[6] Klimza T.: Badanie charakterystyk przepływowych i systemów zabezpieczeń palników gazowych instalowanych w piecach grzewczych. Praca magisterska. Katedra Energetyki Procesowej Politechniki Śląskiej. Katowice 2002.

[7] Klimza T.: Badanie charakterystyk przepływowych i systemów zabezpieczeń palników gazowych zainstalowanych w piecach grzewczych. Międzynarodowa Konferencja Studencka „Metalurgia 2002”. Technicka Univerzita. Kosice.

[8] Palniki przemysłowe gazowe. Wymagania ogólne. PN-86/M-35001.

[9] Palniki przemysłowe gazowe. Badania. PN-88/M-35002.

[10] Palniki przemysłowe gazowe. Palniki zapalające i pilotujące. PN-89/M-35003.

[11] Tomeczek J., Rozpondek M., Góral J.: Charakterystyka przepływowa palników gazowych do wysokotemperaturowych pieców przemysłowych. Hutnik – Wiadomości Hutnicze 2002, nr 5, p. 217-219.

[12] VasziZs., Švab J., Varga A., Jablonsky G., Kizek J., Lazić L.: Mathematical and Physical Model of the Mixers of Air/Fuel and Oxygen Enriched Air/Fuel Burner. In.:The holistic approach to environment, Vol. 1 No. 3, 2011, p. 87-96, ISSN: 1848-0071

[13] J. Jandačka, R. Nosek, Š. Papučik, J. Jurkechová: Influence of combustion air and its redistribution to power and formation of emission. In: ActaMetalluricaSlovaca Conference, Vol.2, No.1, 2011, p.69-74, ISSN: 1338-1660